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ANALYSIS OF EARTHQUAKE VULNERABILITY OF THE DEMAK COASTAL AREA BASED ON THE HVSR (HORIZONTAL TO VERTICAL SPECTRAL RATIO) METHOD

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ABSTRACT

This study aims to assess earthquake vulnerability in the Demak Coastal area using HVSR. The parameters for analyzing earthquake vulnerability based on the HVSR method are natural frequency (f_0), amplification (A_0) and seismic vulnerability index (SVI). The study was conducted by measuring the microseismic signal response at 89 locations using a 3-component seismograph and data logger. The results showed that the dominant frequency varied between 0.26 - 5.26 Hz, the amplification factor varied between 0.51 - 3.56 and the seismic vulnerability index varied between 0.14 - 14.77 $\mu cm^2/s$. The potential for earthquake hazards described by SVI with a range of values 10 < SVI (high classification) is found at observation station 60 (Dusun Bedono) and observation station 70 (Karangwaru Hamlet grave). Based on this research, the government or related communities are urged to be more aware of the dangers caused by earthquakes so that the government and community are urged to avoid locations that are indicated as dangerous, or to build earthquake-resistant buildings in areas that have moderate to high SVI.

Keywords: Demak Coast; HVSR; Seismic Vulnerability; Disaster Mitigation

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INTRODUCTION

Most of the Demak Regency area, especially on the north coast, has a subsurface structure in the form of alluvium which is a fairly thick deposit, because it was originally a swamp. So that in the rainy season the north coast of Demak is often hit by floods and in the dry season the land cracks because it comes from a muddy soil structure [1]. Demak Beach, which used to be a former swamp land so that it has a flat morphology, and the increase in sea water every year, causes several villages in Sayung District, including Sriwulan, Tambakroto, Gemulak, Bedono, Tugu, Surodadi, Banjarsari, Sidorejo and others to experience the impact of tidal flooding. In addition to tidal flooding, unstable soil structures will make the area prone to land movement, especially movement caused by earthquakes. Damage caused by earthquakes is commonly called seismic hazard [2].

Research on the seismic vulnerability index in the Demak area is important because the Demak area has a thick alluvium structure. This will make the area have a high seismic vulnerability value if supported by the existence of a high amplification factor in the area. Earthquake hazard analysis is very important to provide a general description of the earthquake-prone zone and land deformation due to vibrations that occur on the earth in the Demak Coastal area considering that there are many faults around it, including the Semarang Fault, Kaligarang Fault, Ungaran Fault, Lasem Fault and Pati Fault which have the potential to occur. Historically, there was a recorded earthquake in the Demak area with a magnitude of 3.4 on January 1, 2010.

The parameters commonly used in seismic vulnerability analysis in an area are the Seismic Vulnerability Index (SVI) [3]. According to Nakamura [4], seismic vulnerability is a value that describes the vulnerability of shallow layers (surface) to deformation during an earthquake. Land deformation can be influenced by the thickness of the sediment layer. The thickness of the sediment layer describes the thickness of the weathering layer on the surface layer of soil above the bedrock. Mala et al. [5] stated that the deeper the bedrock, the easier the soil layer above the bedrock will be deformed by earthquakes. The maximum ground acceleration value is the value of the largest ground vibration acceleration in an area due to an earthquake that has ever occurred in the area [6].

The microseismic method can be used to determine the value of natural frequency, amplification and seismic vulnerability in an area [7-8]. The value of natural frequency is inversely proportional to earthquake vulnerability, the lower the value of natural frequency, the higher the value of earthquake vulnerability in the area. The microseismic method can be used to estimate the depth of bedrock and describe the thickness of the sediment layer or weathering layer that covers the bedrock. The deeper the bedrock, the higher the value of seismic vulnerability [9]. Similar research was presented by Nurwidyanto [10], the study explained about microzonation for seismic hazard using the microtremor method in Semarang.

This research focuses on the study and analysis of earthquake hazards to determine the dominant frequency, amplification factor and seismic vulnerability index (SVI), using the HVSR microseismic method so that it can be used as information for earthquake disaster mitigation in the coastal area of Demak.

METHOD

Microtremor and Horizontal to Verticl Specral Ratio (HVSR)

Microtremor can be interpreted as a natural harmonic vibration of the ground that occurs in layers of rock sediments. These harmonic vibrations can experience reflection as a result of the existence of boundary layers with a constant frequency. Apart from that, these harmonic vibrations can also be caused by micro-vibrations below the ground surface or other natural phenomena. According to the results of a study in the field of seismology by Kanai [11], there is greater wave amplification in softer lithology compared to harder rock. The result of this will be that softer rock types are at greater risk if there are earthquake shock waves.

Apart from amplifying microtremor waves, it can be used to determine the level of soil hardness obtained using natural period values. If the value of the natural period is small then it can be concluded that the hardness of the soil is high and conversely, if the soil is soft then the natural period will have a large value. Nakamura [3] showed that the ratio of the horizontal spectrum to the vertical spectrum of the microtremor will increase at the resonant frequency and show a peak at that frequency assuming that H/V can reflect the level of amplification from the ground. The advantage of the HVSR method is that the measurement does not require data recording in the bedrock area [3].

The HVSR method's basic idea is to compare the microtremor waves' horizontal and vertical component spectra while ignoring surface waves (Rayleigh and Love waves) and assuming that the majority of microtremor waves are shear waves. The amplification value and dominant period value at a location can be estimated from the peak period of the microtremor H/V ratio [12]. According to Nakamura [3], this approach is an analysis technique based on observations of the shear wave propagation resulting from earthquake events for different geological circumstances. Generally speaking, the HVSR method is a passive seismic approach that employs three components for its measurements: one vertical component and two horizontal components, or East-West and North-South. Natural frequency and amplification are significant outcomes of the HVSR approach, according to Herak [13], these parameters can be utilized to ascertain local geological features, natural frequencies, and amplification associated with the physical attributes of subsurface rocks.

Frequencies that frequently appear can be called dominant frequencies and these frequencies can be considered as natural frequency values for the rocks in that area. Rock properties can be described using the research area's known frequency values. An area's frequency value is influenced by the average subsurface velocity and the thickness of the sediment layer [12]. When an earthquake or vibration occurs in a region at a frequency that coincides with the natural frequency, it will create a resonance and intensify the seismic waves in that region.

Dominant Frequency

Dominant frequencies are those that occur frequently; the rocks in that area can be thought of as having natural frequency values for these frequencies. Rock properties can be described using the research area's known frequency values. An area's frequency value is influenced by the average subsurface velocity and the thickness of the sediment layer [12]. When an earthquake or vibration occurs in a location at the same frequency as the natural frequency, it will create a resonance and intensify the seismic waves in that area.

Amplification Factors

Amplification can occur due to the contrast in wave propagation parameters (density and speed) between the bedrock and sediment in the upper layer. This amplification value is related to the comparison of the impedance contrast of the rock layers, so that when the impedance contrast of the two layers is high, the amplification value will be higher and vice versa [12]. The amplification factor can explain the change or increase in the acceleration of ground movement from the bedrock to the ground surface which is caused by differences in the speed of shear wave movement (v_s) in the bedrock and soil layers (sediment). The v_s value from the bedrock to the surface will become smaller and will cause the shear modulus and damping factor values to decrease so that the ground acceleration value will be greater. The increase in the acceleration of ground movements on the surface is shown by the increasing amplification value [14]. According to Arifin [15], the amplification value can be written as a function of comparing contrast values with the following equation:

$$A_0 = \frac{\rho_b V_b}{\rho_s V_s} \quad (1)$$

ρ_b is the density value of the bedrock (g/cm^3), ν_b is the wave propagation speed in the bedrock (m/s), ρ_s is the mass density of soft rock (g/cm^3), and ν_s is the wave propagation speed in soft rock (m/s) [15].

One important parameter that is closely related to the level of vulnerability of an area from the threat of the seismic vulnerability index is a significant factor that is intimately linked to how vulnerable a region is to the possibility of earthquakes. The degree of danger that an earthquake would cause damage can be directly correlated with the value of the seismic vulnerability index. An increased danger of earthquakes in the area is indicated by a high value for the seismic vulnerability index. When determining an area's seismic vulnerability index value, one consideration that must be made is the local geological conditions [16]. Areas with low natural frequencies typically have high seismic vulnerability index scores. This suggests that the seismic vulnerability index of the thick sediment layer above the bedrock layer is high. In Hadi et al [17], thick sediment layers can produce high vulnerability index values if accompanied by seismic shear wave amplification.

$$K_g = \frac{A_0{}^2}{f_0} \quad (2)$$

where K_g is the seismic vulnerability index value, A_0 is the peak value of the microtremor spectrum (amplitude), and f_0 is the magnitude of the resonance frequency.

Table 1. The classification of f_0 values [11]

Soil Classification	Dominant Frequency (Hz)	Soil Description
Type I	6.67 – 20	Tertiary or older rocks. Consisting of hard gravelly sandstone
Type II	4 – 6.67	Alluvial rock with a thickness of 5m. Consists of gravelly sand, hard sandy loam, clay, and clay
Type III	2.5 – 4	Alluvial rocks are almost the same as type II soil, only distinguished by the presence of unknown formations
Type IV	< 2.5	Alluvial rocks are formed from delta sedimentation, top soil, mud, soft soil, humus, delta sediment or mud deposits, which are classified as soft soil as deep as 30 m.

The seismic vulnerability index is a significant factor that is intimately linked to how vulnerable a region is to the possibility of earthquakes. The degree of danger that an earthquake would cause damage can be directly correlated with the value of the seismic vulnerability index. An increased danger of earthquakes in the area is indicated by a high value for the seismic vulnerability index. When determining an area's seismic vulnerability index value, one consideration that must be made is the local geological conditions [16]. Areas with low natural frequencies typically have high seismic vulnerability index scores. This suggests that the seismic vulnerability index of the thick sediment layer above the bedrock layer is high. If the surface wave and frequency values are higher, the vulnerability value will be lower; conversely, if the amplification value is higher, the vulnerability value will also be higher [18]. Table 2 displays the seismic vulnerability levels classified for this investigation.

Table 2. Classification of Seismic Vulnerability Values

Zone	Classification	Seismic Vulnerability Value
1	Low	$SVI < 5 \times 10^{-6}$
2	Medium	$5 \times 10^{-6} < SVI < 10 \times 10^{-6}$
3	High	$SVI > 10 \times 10^{-6}$

Procedure of Research

Earthquake vulnerability research in the coastal area of Demaik was conducted by taking measurements at 89 microtremor stations as explained in Figure 1. The location of the Demak Coast was chosen because no one has studied seismic vulnerability, besides, according to Pusgen 2017 around Demak there are locations of fault l, Pati fault, Semarang fault, Kaligarang fault, Ungaran fault which have the potential to be earthquake sources. The research coordinate boundaries are limited to the UTM coordinates of zone 49 443375E 9226641S to 454839E 9245119S. The distance between microtremor stations at the research location varies around 1.3 - 2 km so that 89 measurement stations are obtained, besides that time and funds are considered, but they already represent the coastal area of Demak. Figure 1. explains the sub-district boundaries and 89 research location stations. Some of the equipment used are 2 sets of microtremor tools using data loggers, 3-component digital seismograph VHL PS 2B, global positioning system (GPS), and compass to determine the North direction from the data collection results. The software in this study is Notepad++, Microsoft Excel, QGIS, and Geopsy [10],[19].

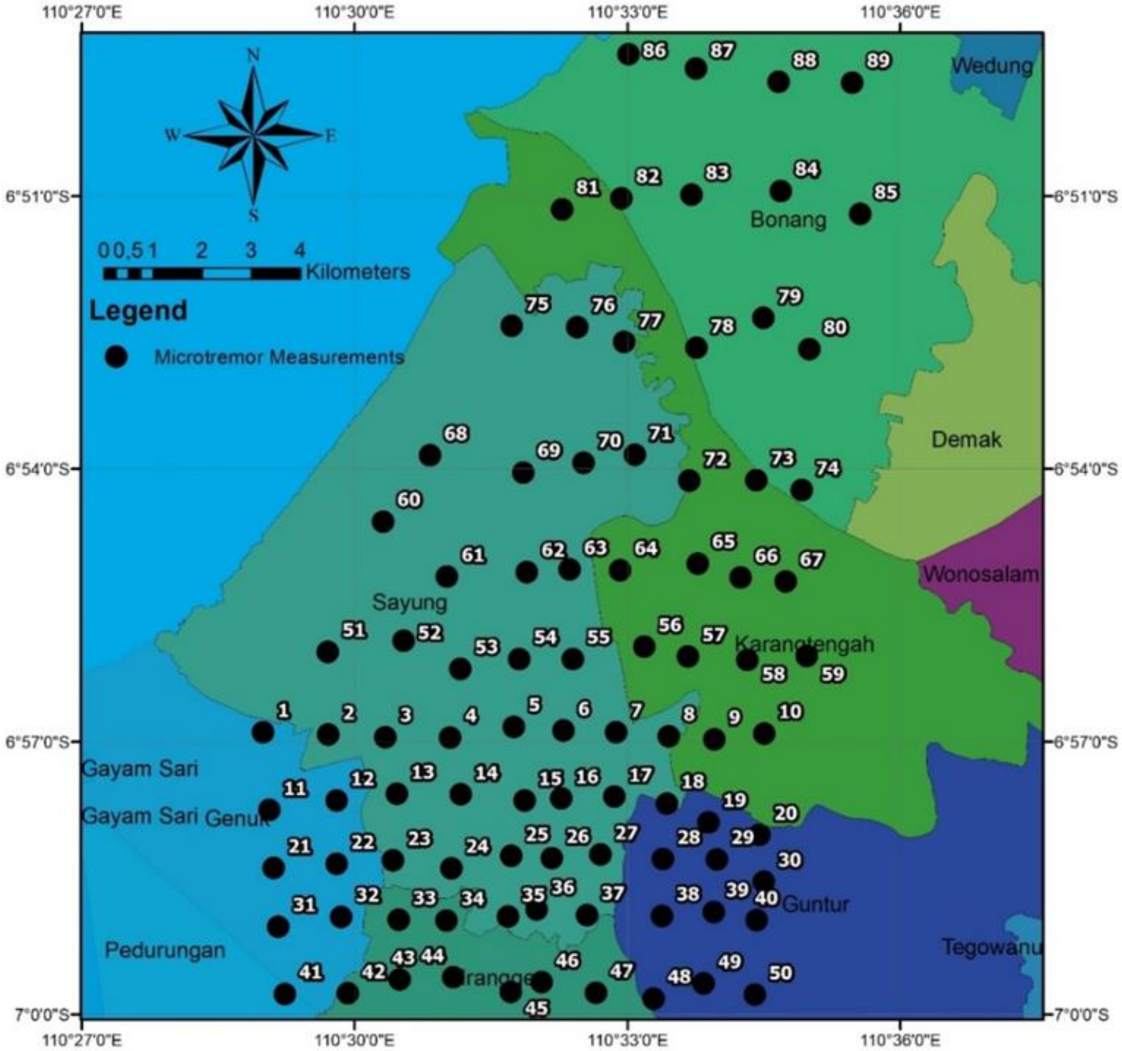

Figure 1. Location of microtremor measurement in Demak Coastal Area

Raw microtremor data will be obtained in the form of a .CSV file containing microtremor signals as in Figure 2 and Figure 3. This data shows the microtremor response in displaying subsurface images with several components, namely the East-West horizontal component, the

North-South horizontal component, and then the vertical component. These three components can be processed using geopsy to obtain the dominant frequency, the HV curve depicted in Figure 4, and the amplification factor [20-21], which are then utilized in equation 2 to produce the seismic vulnerability index value.

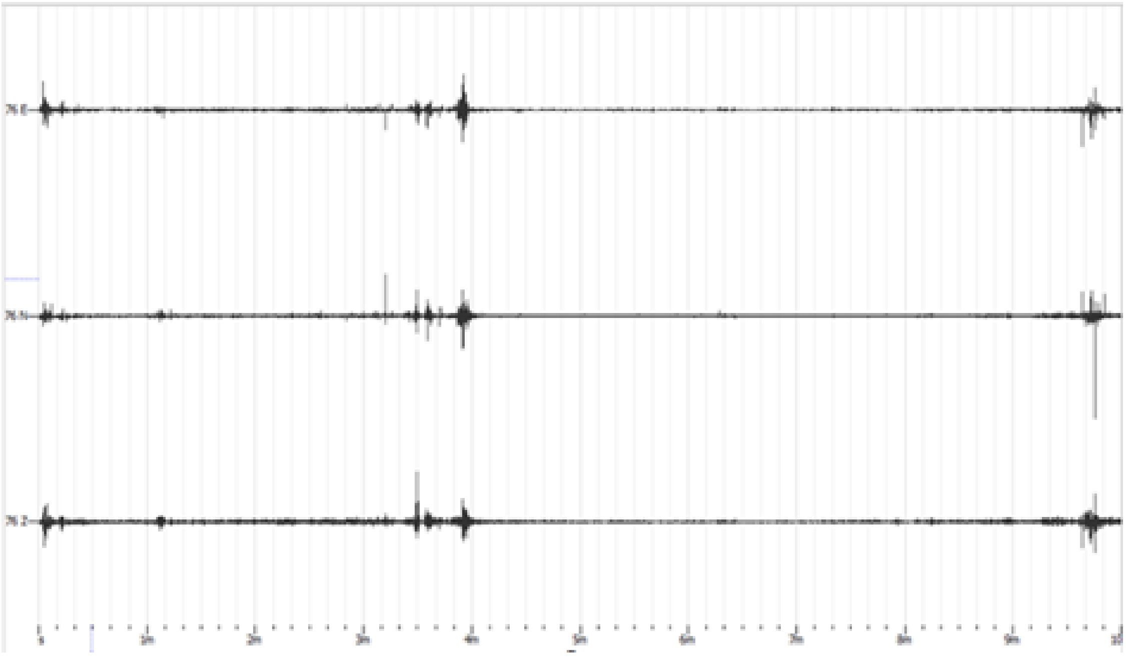

Figure 2. Microtremor signal in poin 60

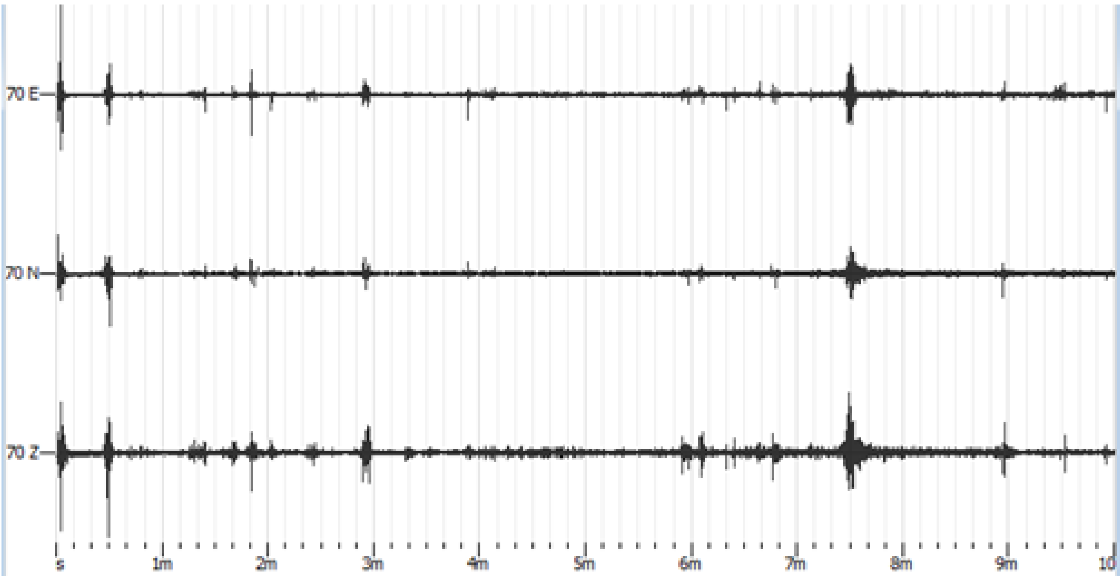

Figure 3. Microtremor signal in point 70

The raw data results from the data logger on the GL tool are excel data which are then moved first to notepad and saved in .txt format so that data processing can be carried out by the Geopsy software. The data is then processed using the HVSR method. The parameters used in data processing are time window length, Short Term Average, Long Term Average, and anti-triggering which is used to detect and eliminate transient signals. The processing of this method also uses the Kohno & Ohmaci smoothing type because this smoothing type can produce the right output for low frequencies [22]. The hv curve from station 60 is shown in Figure 4(a)., while the hv curve from station 70 is shown in Figure 4(b). After the HVSR technique processing is complete, 2D modeling can be used to determine the seismic vulnerability index, amplification factor, and dominant frequency conditions in the coastal area of Demak.

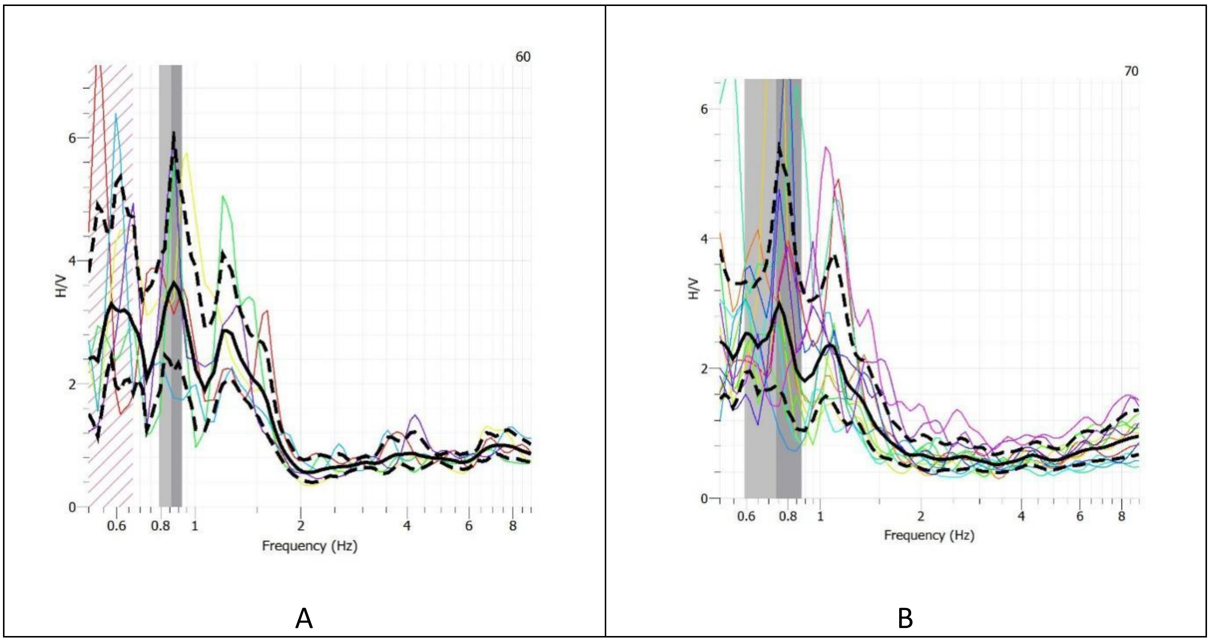

Figure 4. Curve HV in point 60 (A) and in point 70 (B)

RESULTS AND DISCUSSION

Dominant Frequency

The frequency value of the rock layers in a region can be inferred from dominant frequency, which can be understood as a frequency value that occurs frequently. The Kanai Classification [11] is the predominant frequency classification used in this investigation. According to the Kanai classification, hard rock predominates and surface layers are thinner at higher frequencies. Conversely, a larger thickness and softer sediment are associated with a smaller dominant frequency value. Over an extended period of time, an area's susceptibility to earthquakes may rise due to a low dominant frequency value. This is due to the possibility of damage caused by earthquake waves becoming trapped in sedimentary strata. In the Demak area, the major frequency value falls between 0.26 and 5.26 Hz. The Demak area has a dominating frequency of types 2, 3, and 4, as shown by the dominant frequency values in Figure 5. With the classification of alluvial rocks generated by sedimentation, top soil, and mud deposits that are included in the soft soil, mud, and humus 30 meters deep or more, Type 4 exhibits a very thick layer of surface sediment. This is consistent with Demak's geological conditions, which are alluvial because of its proximity to the ocean. Microtremor stations 21 and 30 are home to type 3 and station 40 is home to type 2 earthquakes.

Amplification Factors

If a seismic wave moves from one media that is harder than the first one it passed through to another, it may become more powerful. The seismic waves are amplified to a larger extent with increasing layer difference. Larger and more destructive earthquake shock waves can result from a location with a high amplification factor. Wave speed has an impact on amplification.

The presence of massive waves is indicated by a high amplification value. This demonstrates a connection between a rock's density and amplification factor. The value of the amplification factor in a region will rise as the density of rock decreases [15]. The amplification factor (A_0) value in the Demak area ranges from 0.51 to 3.56. The Amplification Factor value in the Demak area shown in Figure 6 has a classification with a value of $A_0 < 3$. This shows that in this area the earthquake wave shocks are not getting bigger due to the presence of

In the Demak area, the amplification factor (A0) value varies from 0.51 to 3.56. A0 < 3 is the classification of the Amplification Factor value in the Demak area depicted in Figure 6 This demonstrates that the strong amplification in this region prevents earthquake wave shocks from growing larger and causing more significant damage. Bedono hamlet is the only locality with a categorization of 6 > A0 > 3. Because of its moderate earthquake amplification category, this place warrants caution.

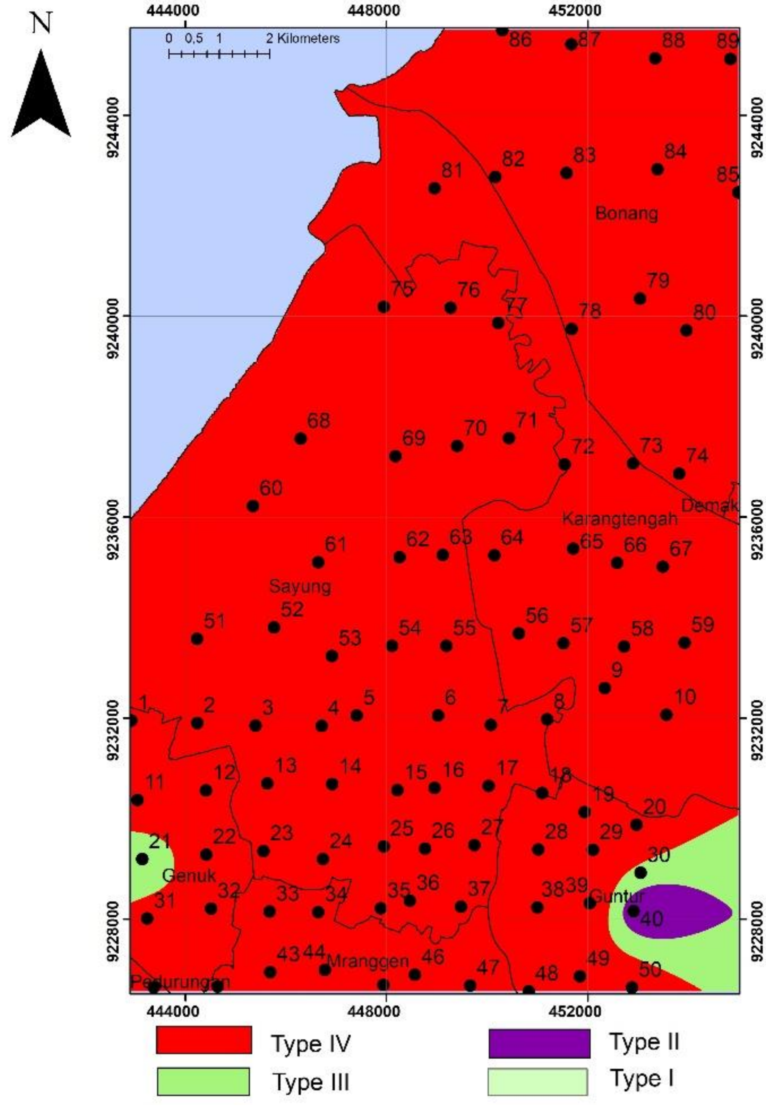

Figure 5. Dominant frequency values in the research area

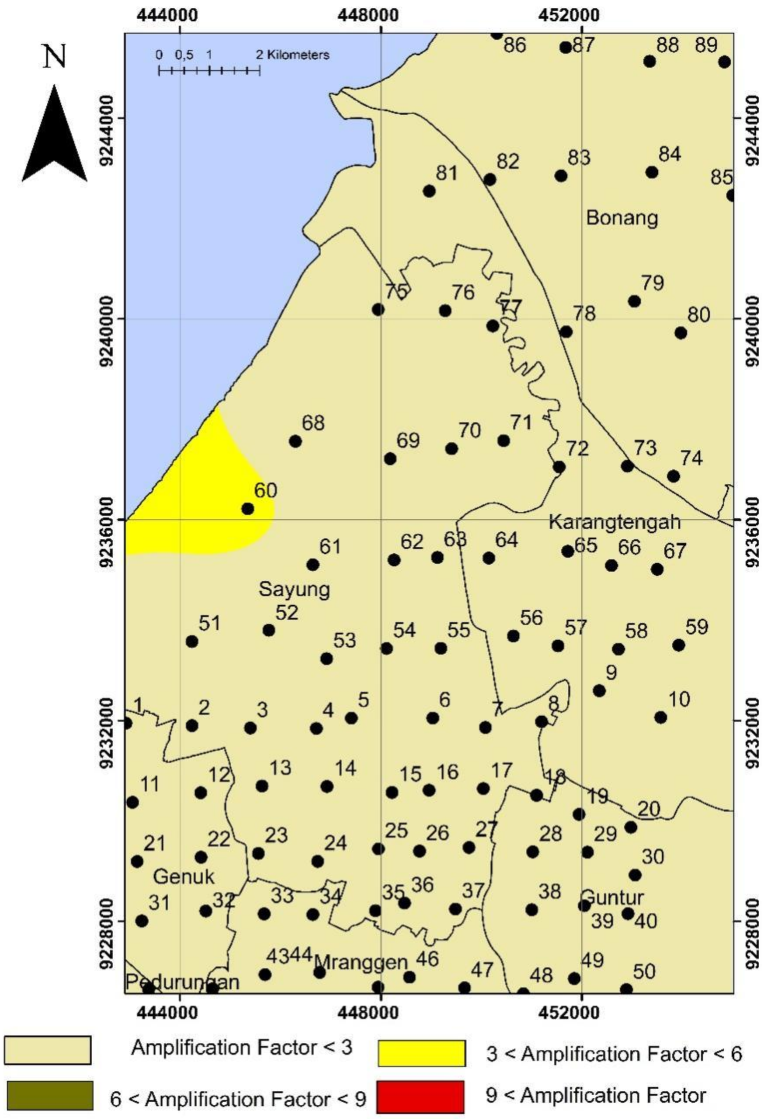

Figure 6. Amplification Value in the research area

Seismic Vulnerability Index (SVI)

One way to view the seismic vulnerability index (Seismic Vulnerability Index) is as a metric that may be used to determine how vulnerable a location is to ground movement [3]. The degree of risk that can be posed by ground movement in this case, an earthquake is related to the seismic vulnerability index. An earthquake's potential impact and hazards increase with the area's seismic vulnerability index value. The thickness of the sediment layer beneath the ground surface, the speed of surface waves, and the speed of waves below the ground surface are used to calculate the seismic vulnerability index value. Thus, it may be said that a territory's overall level of vulnerability can be inferred from the value of land vulnerability in that region.

The Seismic Vulnerability Index value in the Demak area ranges from 0.14 to 14.77 $\mu cm^2/s$. Based on Figure 7, low classification in zone 1 with a value range of 5 $\mu cm^2/s$ > SVI is found in most of Demak. Medium classification is in zone 2 with a value range of 5 $\mu cm^2 / s$ < SVI < 10 $\mu cm^2/s$ found in stations 4, 8, 12, 14, 19, 46, 54, 71, 75, 76, 78, 86. High classification with a value range of 10 $\mu cm^2/s$ < SVI is found at stations 60 (Bedono hamlet) and 70 (Karangwaru hamlet cemetery).

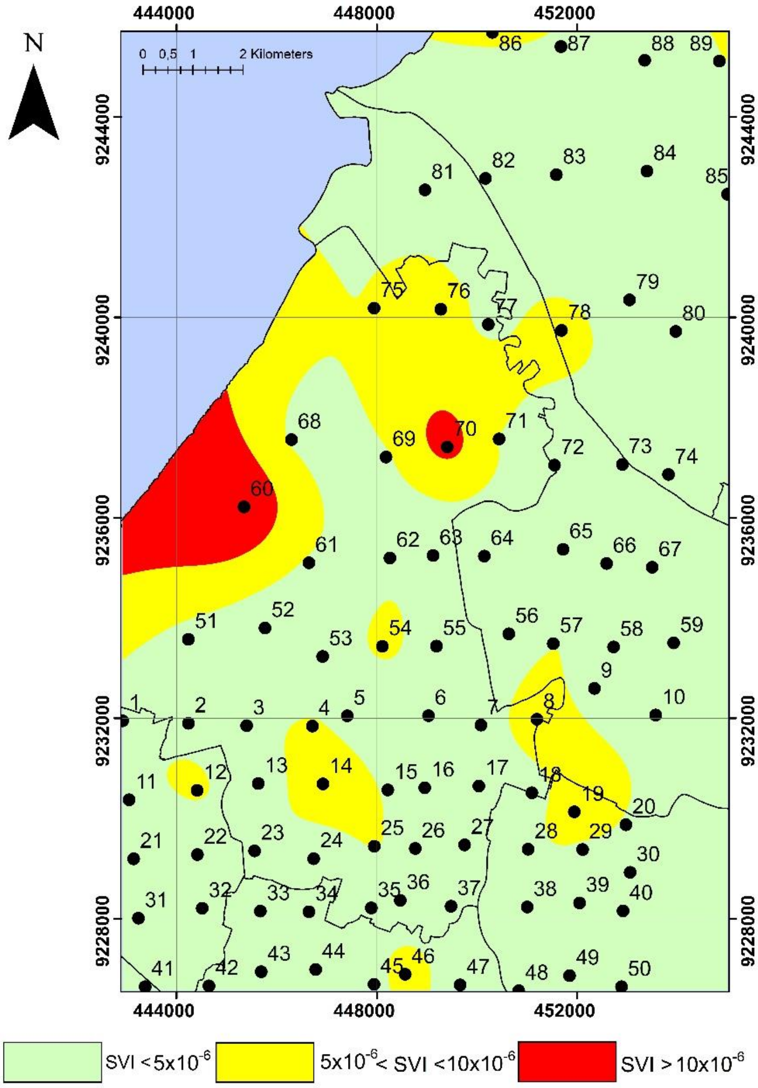

Figure 7. Seismic Vulnerability index (SVI) Map of Demak Coastal Area

Based on the dominant frequency value in the coastal area, it has a low classification value. This can occur due to the presence of quite thick alluvium in the coastal area of Demak. Most of the dominant frequency values are fortunately not supported by high amplification values. However, in certain areas shown in yellow and red in Figure 7, they have a fairly high seismic vulnerability index. If there is a low dominant frequency and a high amplification value, it will cause the area to have high seismic vulnerability. Conversely, if there is a high dominant frequency and a low amplification value, it will cause the area to have low seismic vulnerability because it is an area that has shallow bedrock with small amplification. The value of the dominant frequency does not always have an inverse relationship with the amplification value. Both values depend on the conditions and structures in the field. Microtremor stations 21 and 30 detected type 3 and station 40 detected type 2. Stations 60 (Bedono hamlet) and 70 (Karangwaru hamlet cemetery) have the potential to experience earthquakes with a value range of 10 $\mu cm^2/s$ < SVI (high categorization), thus if an earthquake occurs, this region has to be informed. Research related to the seismic vulnerability index in coastal areas was also conducted by Nurwidyanto [10] located in Semarang (west of this research area). The study also showed that there was a small dominant frequency in coastal areas which are alluvium areas.

The seismic vulnerability index in the study had a range of values 0.41– 140.27 μcm²/s varying as in Nurwidyanto [10] study.

CONCLUSION

The Demak coastal area as a whole has a tiny dominant frequency, which arises because the area has an alluvium with thick and soft silt. This association between the dominant frequency, amplification factor, and seismic vulnerability index is derived from the research findings. Microtremor stations 21 and 30 detected type 3 and station 40 detected type 2. Stations 60 (Bedono hamlet) and 70 (Karangwaru hamlet cemetery) have the potential to experience earthquakes with a value range of 10 μcm²/s < SVI (high categorization), thus if an earthquake occurs, this region has to be informed. Based on this research, the government or related communities are urged to be more aware of the dangers caused by earthquakes so that the government and community are urged to avoid locations that are indicated as dangerous, or to build earthquake-resistant buildings in areas that have moderate to high SVI.

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